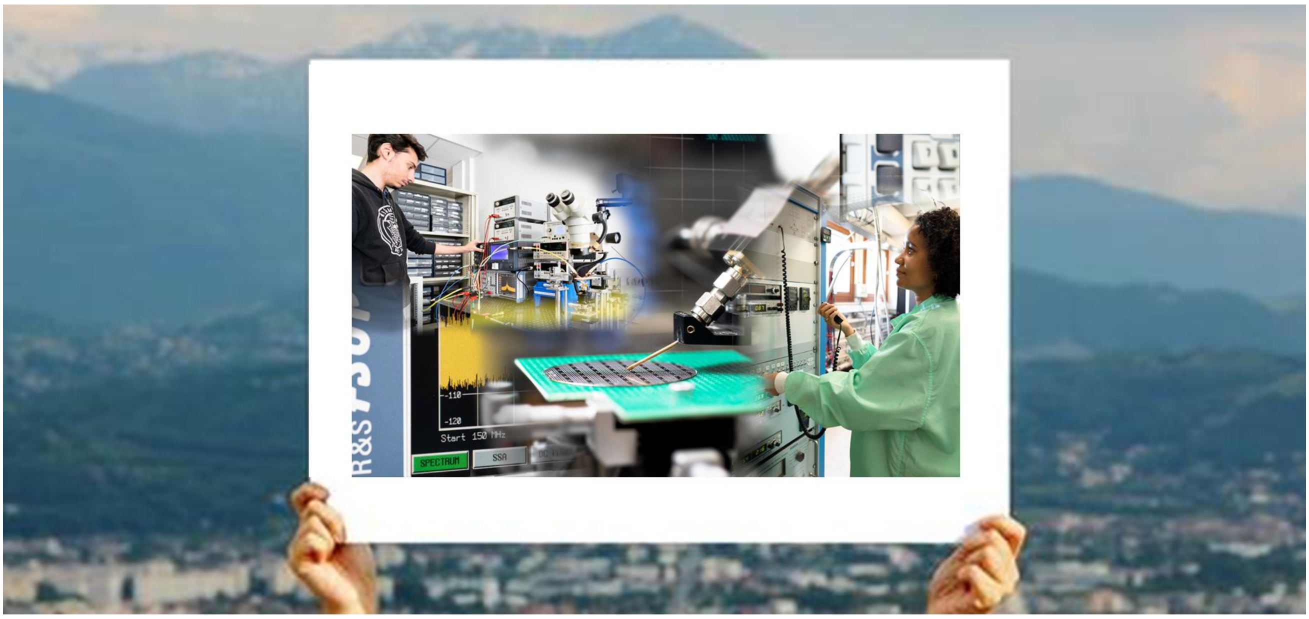
SPINTRONIQUE et TECHNOLOGIE des COMPOSANTS

Master Internship Booklet

2027



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SPINTEC IN BRIEF

SPINTEC is one of the leading spintronics research laboratories in the world, positioned at the crossroads of science and technology. SPINTEC is hosted on the MINATEC campus in Grenoble. The international city of Grenoble is located in the French Alps and surrounded by an exceptional natural environment. It is also an extremely rich ecosystem formed by public research organisations (CEA, CNRS, ESRF, ILL) and the University of Grenoble Alpes (UGA), as well as numerous high-tech companies.

SPINTEC was created 20 years ago and has grown rapidly to now exceed 100 people, including 58 permanent staff from CEA, CNRS and the University of Grenoble-Alpes, and working cooperatively in an open structure organized around focused research topics.

SPINTEC's mission is to act as a bridge between academic research and technological applications in the field of spintronics, which is both a very rich source of new condensed-matter-magnetism physics, and recognized today as one of the major innovation routes for future microelectronics industries, information and communication technologies, sensing technology and bio-applications. As such, we are at the cross-road of nanosciences and technology, conducting our activities in collaboration with academic and industrial partners from all around the world. As such, the laboratory's markers are not only high-rank publications and communications in international conferences, but also the creation of a consistent patent portfolio and the implementation of relevant functional demonstrators and device nanofabrication. The laboratory has launched six start-ups in the last 15 years. This synergy has placed SPINTEC at the forefront of spintronics research, with a crucial contribution to the discovery of new key fundamental effects. These underpin the emergence in the industry of spintronic memories called MRAM, on which the laboratory holds key patents.

The research activity of SPINTEC covers the whole spectrum from theory to demonstrators, including the development of innovative functional materials, the experimental validation of novel concepts in physics, up to the realization of test structures. Academic research concerns spinorbitronics, spintronics in 2D materials, non-linear magnetization dynamics and magnonics, antiferromagnetic spintronics, and exotic spin textures. The application-oriented topics are: magnetic random access memories, artificial intelligence, microwave components, design of spin-based integrated circuits, sensors, and biotechnology. For more information check out our website www.spintec.fr.

SPINTEC FOR YOUR MASTER OR PHD PROJECT

With the objective to train tomorrow's researchers in an active and growing research field, SPINTEC proposes every year topics for (paid) Master projects. The majority of the Master projects lead over to a PhD thesis project with financial support coming from a variety of funding sources, either from research institutions (bourses "*ministère*", CFR CEA, local foundations), academic contracts (ANR, EU) or industrial partners (bourses CIFRE).

At SPINTEC, you will find a dynamic and multicultural environment, which provides all facilities to advance your research project, and get yourself known in the academic world via participation at international conferences, and develop a wealth of personal skills through collaborative work. One year after defending their PhD, close to 95% of our students have a position, with equal shares in the academics and in the industry, half of them with an indefinite-term contract.

Come and join us to be part of those who like to revolutionize condensed-matter research and unlock new microelectronics applications!

List of proposals

The laboratory is constantly seeking undergraduate and summer students with high potential and a taste for research at the frontier between fundamental physics and technology. Individuals with cutting edge scientific skills, strong motivation, the taste for teamwork and a good sense of humor are welcome.

Below is the list and description of projects that are proposed for the Master-2 level, most of them are intended to continue to a PhD, and several are also open to Master-1 level students. In the framework of French universities the typical period for M2 internships is from March to June / July, but we welcome equally students from foreign universities and different timeframes for carrying out their internship.

Please do not hesitate to contact us any time if you are a student and wish to join, either through the lab directors or directly through the permanent staff whose e-mail you find at the end of the corresponding description of the research projects.

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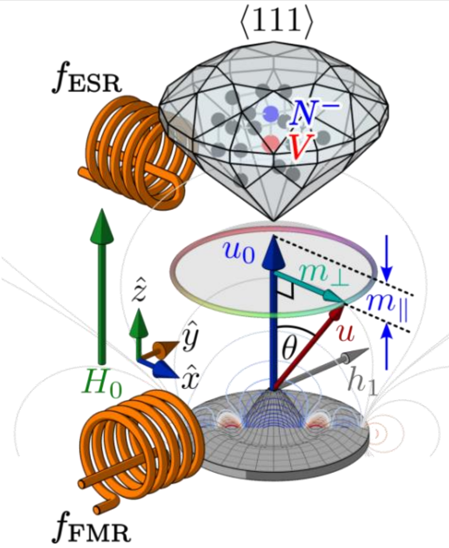
Spin-wave spectroscopy by a single paramagnetic center

Context



The extensively studied notion of conservation of spin angular momentum by conduction electrons in solids is only a restricted part of a much larger story. According to Noether's theorem, angular momentum conservation is a fundamental property that emerges directly from rotational invariance; meaning it applies equally to other particles such as photons, phonons, and magnons, which can be classically represented as circularly polarized vector fields propagating with helical or rotational wavefronts. For photons, this topic has already attracted considerable attention due to its implications for telecommunications. This additional degree of freedom makes it possible to increase the maximum information transfer rate, for instance through mode-division multiplexing: different modes carrying different angular momentum propagate independently, without significant interference, owing to their orthogonality. These modes can therefore be modulated independently, increasing the maximum transfer rate in proportion to the number of modes used. In the quantum regime, angular momentum can be used to encode arbitrarily large $n_J\hbar$-quanta within a single state. While the total angular momentum can, in certain cases, be separated into spin and orbital components, most work has so far focused on the spin component, which reflects the circularly polarized character of vector fields ($n_S = \pm 1$), while the orbital component has remained largely unexplored: a knowledge gap stemming from the broader difficulty of coupling directly to azimuthal waves with large orbital indices.
The goal of this internship is to study these hidden azimuthal modes using a scanning NV-microscope, which provides exquisite spatio-temporal resolution. Our long-term objective is to develop a high-performance orbital-angular-momentum transducer between photons, magnons, and phonons, using a micron-sized, cylindrically shaped magnetic garnet crystal.
Bibliography: T. Valet et al., PRB 113, L100410 (2026) and PRB 113, 104437 (2026)

Work program & Skills acquired during internship

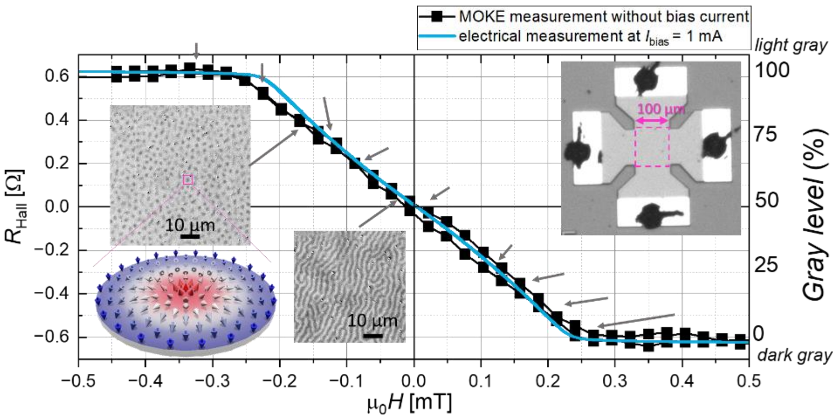
The student will work on a home-built NV-center microscope, specifically optimized for spin-wave spectroscopy. Three patents have been filed on the original design, and the setup has already demonstrated unsurpassed spectral resolution. This project is particularly well suited to tech-savvy students who enjoy a hands-on, "nuts and bolts" approach to experimental physics. By the end of the internship, the student will have gained a broad range of experimental skills spanning optics, microwave technology, mechanics, analog electronics, and computer interfacing in Python. Prior experience with home-built experimental setup (e.g. hardware electronics: rasberrypi, Arduino, or FPGA) will be considered an asset. This internship will lead to a PhD position on the same research topic.
Level: Master 2 student in Solid State Physics, Quantum Physics, Applied Physics, or Electrical Engineering.

www.spintec.fr 17 avenue des martyrs 38054 GRENOBLE cedex 9 Contacts oklein@cea.fr	Requested background: Master 2 Duration: 6 months Start period: Nov 2026/ March 2027 Possibility of PhD thesis : YES

Development of a skyrmion sensor for the detection of neuron activity

Context

Magnetic sensors represent one of the most important applications of spintronics and are widely employed for modern technologies ranging from industrial automation and automotive systems to biomedical diagnostics and space exploration. The performance of magnetic sensors is ultimately determined by their detectivity, defined as the ratio between the noise and the sensitivity.
Magnetic textures, such as skyrmions and stripe domains provide an attractive alternative to conventional uniformly magnetized sensing components because of their exceptional sensitivity to weak magnetic fields and electric currents. Owing to their low depinning fields and rich dynamical behavior, they have recently attracted considerable attention for memory, logic, neuromorphic computing, and magnetic sensing applications. We have recently shown that fields as low as the nanotesla may be detected at low frequency by sensor based on these magnetic textures.
In the present project, we propose to explore the influence of the skyrmions and domain walls behaviour on the sensor functionality. Then, we plan to adapt the sensor to measure the magnetic field created by neurons. For this, in collaboration with the Grenoble Institute of Neuroscience, we will design and fabricate a platform combining the usually used electrodes with our developed skyrmion sensors to detect neuronal activity.



Caption: MOKE signal (black) and Hall resistance (blue) as a function of an applied perpendicular magnetic field. In the bottom left, MOKE images acquired at selected field values show either stripes (at zero field) or skyrmions (around -0.18mT). The magnetic moment arrangement of a skyrmion is schematically represented below the image. The Hall-bar cross is represented in the top right.

Work program & Skills acquired during internship

The M2 student will be integrated in a team of 6 people with daily support and weekly meetings. This project is part of a collaboration with 3 other labs in France where some experiments will be conducted.
Within this experimental internship, we propose to study and develop the skyrmion sensor:

- Fabrication of Hall bar crosses with skyrmion hosting layers (lithography, evaporation) in the clean room available in at Spintec
- Measurements of the sensor response to the field and of its noise under various conditions (AC field, AC bias current, temperature variations…) on a dedicated setup.
- Adaptation and implementation of the skyrmion sensor in a platform to detect the magnetic field created by neurons, in collaboration with Grenoble Institute of Neuroscience.

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Requested background: Master 2
Duration: 4-6 months
Start period: Feb/ March 2027
Possibility of PhD thesis: YES

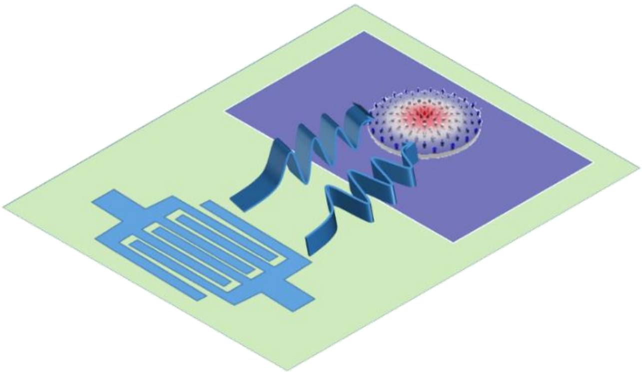
Towards control of magnetic skyrmions by surface acoustic waves

Context

Magnetic skyrmions in thin films are spin textures across which magnetization follows a cycloid with a unique sense of rotation, called chirality. This specific magnetic configuration can be stabilized in ferromagnetic thin films, sandwiched between films of a heavy metal and an oxide, and presents large interfacial perpendicular magnetic anisotropy (PMA). Additionally, the lack of inversion symmetry allows an antisymmetric exchange interaction called interfacial Dzyaloshinskii-Moriya interaction (DMI). Since skyrmions are topological solitons that can be moved by electrical current, they are currently attracting considerable interest both for the underlying physics and for their applicative potential.

Interfacial magnetic properties are essential for skyrmion stabilization and vary with the nature of the materials, but also with the presence of electric charges or ions at the interfaces with the surrounding nonmagnetic materials. Deformation of the crystal lattice and changes in interatomic distances are also expected to strongly affect these magnetic parameters via magnetoelastic effects.

In the present project, we propose to take advantage of surface acoustic waves to manipulate skyrmions, more particularly to nucleate, move, or erase them. These waves propagate at sound velocity in a given direction along the surface of a piezoelectric material, when an AC electric field is applied. Such a new method for skyrmion manipulation would allow us to take advantage of radio-frequency remote addressing of devices based on surface acoustic waves. The first step that will be addressed in this internship is to study the sensitivity of skyrmions to static strain to decide the best material candidates. Surface acoustic waves will then be injected to nucleate and annihilate skyrmions.



Caption: Creation of a skyrmion in the magnetic stack (purple) using surface acoustic waves (blue arrows) generated by biased interdigitated transducers (blue) on a piezoelectric substrate (green)

Work program & Skills acquired during internship

The M2 student will be integrated in a team of 6 people with daily support and weekly meetings. This project is part of a collaboration with 5 other labs in France where the surface acoustic wave experiments will be conducted.

Within this experimental internship, we propose to develop the control of skyrmions using strain:

- Optimization of material stacks on piezoelectric substrates: magnetometry, magnetic imaging (magneto-optical Kerr effect microscopy, magnetic force microscopy) to observe skyrmions
- Characterization of the sensitivity of skyrmions to static strain: study of their stability, size, density, Brownian motion under strain, applied by a DC bias on the piezoelectric substrate
- Transducers for injection of surface acoustic waves will be fabricated by our partners on samples optimized by the student. The student will have the possibility to visit these labs to assist in the measurements for the characterization of the effect of surface acoustic waves on skyrmions.

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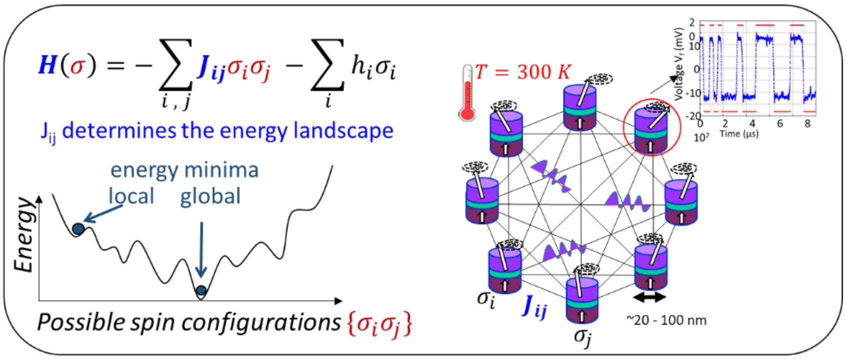
Collective states of a network of coupled spin-torque nano-oscillators for analog computing tasks

Context

Digital computers based on conventional CMOS hardware reach their limits in terms of energy consumption. Novel approaches are under investigation, such as analog computers that exploit physics concepts and reduce overall energy consumption due to their inherent parallel computing capabilities. A powerful example is based on the Ising model, where binary-valued Ising spins σ_i, σ_j are coupled through coupling constants J_{ij}. Depending on the coupling matrix and operational conditions, such an Ising-based analog computing platform can be used for memory, logic, or optimization-problem-solving tasks [1]. This versatility is enhanced when exploiting the intrinsic thermal noise, thus making use of naturally available energy resources to explore the energy landscape.



At SPNTEC, we recently have built such an analog computing platform based on spintorque nano-oscillators [2, 3], which are magnetic tunnel junctions that use spintronics concepts to convert a DC voltage into an oscillating output signal oscillating at RF frequencies. The aim of the internship is to use this analog computing platform to demonstrate the potential for different computing tasks: optimization, logic, or memory tasks. Such implementation requires as a first step a full understanding of the coupled dynamics of spintorque oscillators that will be the focus of this internship.

Work program & Skills acquired during internship

The internship has two options to address the scientific questions: either experimental or by simulation. It will combine fundamental studies of the phase dynamics of coupled spintronics oscillators with electrical characterization of the spintronic network, needed to control the coupling strength and phase. The student will acquire expertise in (i) concepts of spintronics (spin-polarized transport, spin momentum transfer, spin-torque driven magnetization dynamics); (ii) concepts of coupled dynamical systems; (iii) concepts of unconventional computing and (iv) high-frequency measurement techniques. The work is carried out in interaction with the different members of Spintec's RF Spintronics and Artificial intelligence teams.
Interested students, please send a CV and a motivation letter.

[1] Knoll et al. NPJ Unconv. Computing 1, 5 (2024) https://doi.org/10.1038/s44335-024-00005-1; Cai et al. Applied Phys. A 129, 236 (2023) https://doi.org/10.1007/s00339-022-06365-4
[2] N.-T. Phan et al. Phys. Rev. Appl. 21, 034063(2024) DOI: 10.1103/PhysRevApplied.21.034063
[3] A. Hakam et al., https://doi.org/10.48550/arXiv.2606.22208

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Requested background: Master 2 condensed matter physics / nanosciences; good taste for experiments or programming; knowledge of electronic circuits or microwave signal processing is an advantage.
Duration: 4-6 months
Start period: February/March 2026
Possibility of PhD thesis : YES

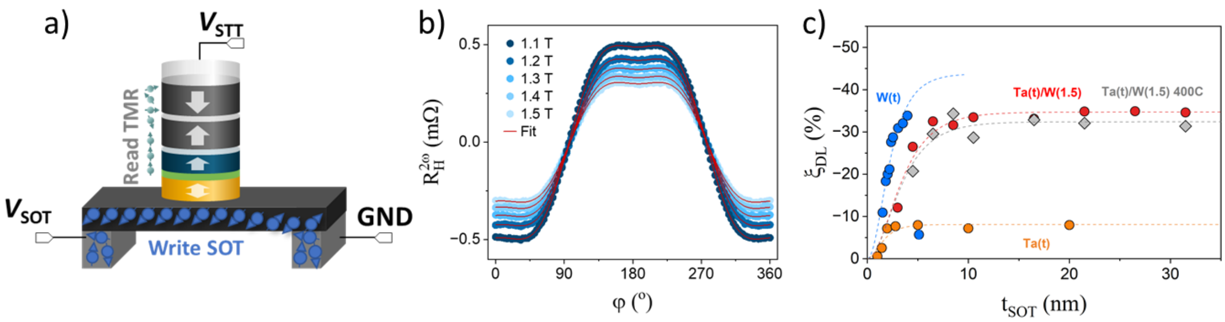
Characterization of orbital and spin-orbital torques for MRAM applications

Context

Spintronic devices exploit the spin, as well as the charge, of electrons and could bring new capabilities to the microelectronics industry, that is facing major challenges related to the volatility of CMOS cache memory elements (SRAM and eDRAM)[1]. Magnetic random access memories (MRAM) devices are among the non-volatile candidates that are low power and fast enough to compete with SRAM. Advanced MRAM devices are magnetic tunnel junctions (MTJ) that are operated by spin transfer torque (STT) effect. Spin-orbit torque (SOT) MRAM has emerged as a credible next-generation MRAM technology that allows for faster and more efficient magnetization writing[2].

In SOT-MRAM devices the ferromagnetic storage layer (FL) is in contact with a non-magnetic heavy metal channel such as Ta, W, or Pt[2]. When a current flows through the channel, a perpendicular spin current is generated and transferred to the magnetization of the FL via spin Hall effect (SHE)and Rashba-Edelstein effect (REE), inducing magnetization reversal. To enable SOT-MRAM as viable technology, several challenges need to be overcome. In terms of material innovation, improving the write efficiency (SOT material, interface) is key. Recently, the SHE and REE have been predicted to arise from more fundamental effects[3], namely Orbital Hall effect (OHE) and Orbital Rashba-Edelstein effect (OREE). These effects can feature greater magnitudes compared to the spin counterpart and they are present in a much wider class of materials, including light metals with low resistivity. Hence, they offer the possibility to integrate more efficient, and more conductive material, possibly reducing the devices power consumption[4].

We propose in this internship to extend our on-going studies[4] studying materials combinations (thickness, compound), in order to improve SOT efficiency and address SOT-MRAM write challenges exploiting novel orbital effects.



a) SOT-MRAM device design, b) Example of spin-orbit and orbital torque characterization in SOT-based devices, c) SOT/OT efficiency for different material systems[4]

Work program & Skills acquired during internship

The internship thesis will consist in:

i. Define stack and characterize magnetic properties (magnetization saturation, anisotropy)
ii. Nano-Fabrication of Hall bars in PTA cleanroom
iii. Characterize spin torques amplitudes as a function of thicknesses and material compounds
iv. Analyze contribution from SOT, OT and other physics, synthetize and report results

[1] B. Dieny et al., “Opportunities and challenges for spintronics in the microelectronics industry”, *Nat. Electron*. 3, pp. 446-459 (2020)
[2] K. Garello et al., “Spin-orbit torque switching of magnetic tunnel junctions for memory applications”, doi.org/10.1016/j.jmmm.2022.169692
[3] D. GO, et al., “Intrinsic Spin and Orbital Hall Effects from Orbital Texture”, Phys. Rev. Lett. 121, 086602 (2018)
[4] M. Biagi et. al, “Orbital and Spin-Orbit Torque Interplay in Ta/W-based Magnetic Tunnel Junctions with Vertical Non-local Switching”, https://arxiv.org/abs/2605.27215 [recent preprint from our group on the topic]

http://www.spintec.fr/	Requested background: Master 1 / Master 2
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Electrical detection of magnetic vortex state

Context

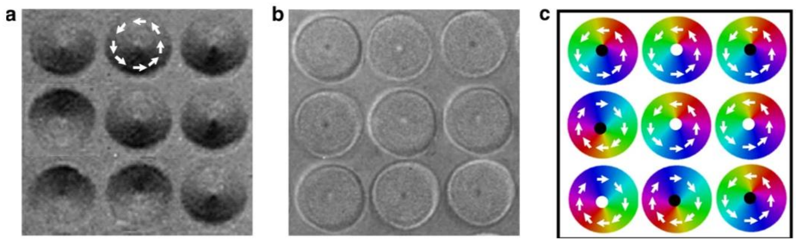

Figure 1. In-plane (**a**) and out-of-plane (**b**) components of vortex magnetization in a 100-nm-thick nanodisks obtained by magnetic transmission soft X-ray microscopy. Schematic illustration of the complete vortex configuration of each nanodisk (**c**). Adapted from: https://doi.org/10.1038/ncomms1978

A magnetic vortex is a micromagnetic structure with concentric, vortex-like redistribution of magnetic moments. This magnetic state appears naturally in thick sub-micron circular disks. Fundamental aspects of vortex state formation and its stability are well covered by theory, simulations, and experimental studies thereby opening a multitude of its applications. Today, magnetic vortex is being implemented in spin-torque oscillators, bio-medical applications, magnetic memory and field sensors. Its linear and nonhysteretic response in a wide range of magnetic fields is particularly attractive for magnetic field sensing. Integrated into a TMR stack, vortex-based sensors are already competing and even overperforming classical solutions based on the Hall effect. Due to this, semiconductor industry considers TMR vortex sensors to serve as contactless electrical current sensing for automotive sector, position/angular sensor for robotic/humanoid applications and linear/threshold magnetic field sensors for consumer electronics. Further advancements are anticipated through the development of novel materials for the TMR stack and the implementation of innovative sensor layout methodologies.

A magnetic vortex has four magnetic states defined by combination of its chirality (clockwise or counterclockwise) and its core polarity (positive or negative). Different variations of magnetically sensitive microscopy (MFM, Lorentz, MOKE etc.) are being used to distinguish these states and account for statistics after vortex re-nucleation. Knowledge and control of vortex re-nucleation is essential for robust TMR sensor performance. The goal of this internship is to detect vortex states electrically to open a convenient way for large scale wafer testing.

Work program & Skills acquired during internship

The internship will involve micromagnetic simulations, wafer level testing, and data analysis. A special TMR stack with pinned vortex layer will be used as a reference electrode. The main phase will be focused on micromagnetic simulations to explore how these four different vortex states are observable in the magneto-resistive response of an MTJ pillar at ambient temperature and eventually under the action of the spin-transfer torque. Using realistic material parameters, the magnetic layers of TMR stack and pillar geometry will be optimized for further nanofabrication. The next phase of the internship project will focus on wafer level testing of nanofabricated devices involving different annealing recipes. Measured data will undergo statistical analysis with the final goal of exploring large-scale vortex state statics and understanding the trends of vortex re-nucleation process in presence of various external factors (magnetic field, temperature, current, etc.).

Student profile: Master 2 in nanophysics/solid state physics, knowledge of Python for data processing and visualization, experience with electrical measurements, basics of magnetism, good mathematical and statistical skills. It will be possible to pursue a Ph.D. thesis on this subject after the internship.

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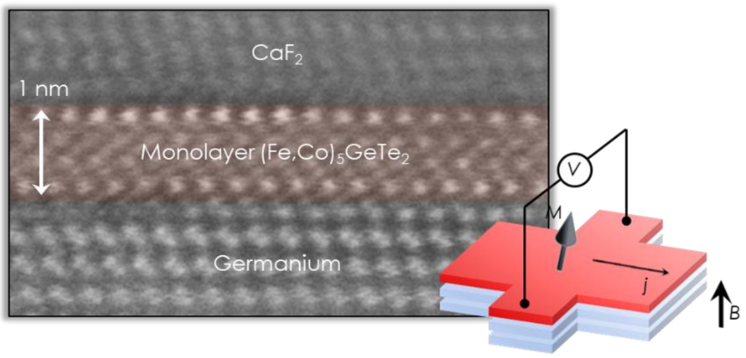
Requested background: Master 2
Duration: 4-6 months
Start period: March 2027
Possibility of PhD thesis: YES

Interplay between charge and spin in 2D magnets

Context

Two-dimensional (2D) magnets present exceptional properties compared to conventional magnetic materials, such as atomically-sharp van der Waals interfaces, thickness-dependent magnetic ordering and the ability to tune their magnetic properties with proximity effects. Among these, Fe_NGeTe_2 alloys stand out due to their remarkably high Curie temperature (T_C), close to or above room temperature. In the past few years, Spintec has pioneered the fabrication of high quality Fe_NGeTe_2 by molecular beam epitaxy and has made significant progress in understanding and controlling magnetic interactions in these materials [1-4]. The team recently achieved record-high T_C thanks to cobalt doping and demonstrated high temperature ferromagnetism down to the strictly 2D limit [3]. These advancements pave the way for integrating 2D magnets in practical devices, such as magnetic memories or sensors.

Indeed, Fe_NGeTe_2 alloys are particularly attractive for spintronics. Their ultraclean interfaces and ultimate thinness make them ideal for controlling efficiently the magnetization with either charge currents (spin-orbit torques physics) or electric fields (gating). Unconventional phenomena such as self-torques have also been predicted in them but await clear experimental demonstration. The objective of the internship will be to investigate these phenomena through magnetotransport experiments in devices made of ultrathin Fe_NGeTe_2 possibly interfaced with nonmagnetic van der Waals materials.



Transmission electron microscopy image of a Co-doped Fe_5GeTe_2 monolayer

Bibliography : [1] Ribeiro et al. npj 2D Mater. Appl. 6, 1 (2022); [2] Sampaio et al., Nano Lett. 25, 14341 (2025); [3] Courtin et al., Phys. Rev. Lett. 137, 046703 (2026); [4] T. Guillet et al., Nano Lett. 24, 822 (2024)

Work program & Skills acquired during internship

The experimental work will involve:
- growth of 2D magnets by molecular beam epitaxy,
- fabrication of gated Hall bar devices by lithography in the clean room present at Spintec,
- magnetotransport experiments in order to probe the magnetic response to electrical excitations as a function of thickness, temperature and gate voltage.

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Requested background: Master 2
Duration: 6 months
Start period: Feb/ March 2027
Possibility of PhD thesis : YES

Manipulation of magnetic skyrmions for neuromorphic computing

Context

Magnetic skyrmions are texture composed of spins that whirl closely to form a topologically stable, chiral structure (see Fig.1 (a-b)). Their size can be as small as a few nanometers. Skyrmions can also be manipulated by electric currents, which has led to novel concepts of non-volatile magnetic memories and logical devices where skyrmions in nanotracks encode the information. The nanometer size of skyrmions, combined with the low current density required to induce their motion, opens a path for devices that combine high storage density, high speed execution and low energy consumption. Important steps toward application was made in Spintec with the first direct observation of magnetic skyrmions at room temperature in ultra-thin Pt/Co(1nm)/MgO multilayer nanostructures [1], the recent demonstration of their fast (>1km/s) manipulation using electrical currents (Fig. 1 a) [2] and their integration in magnetic tunnel junctions (Fig. 1b) [3].

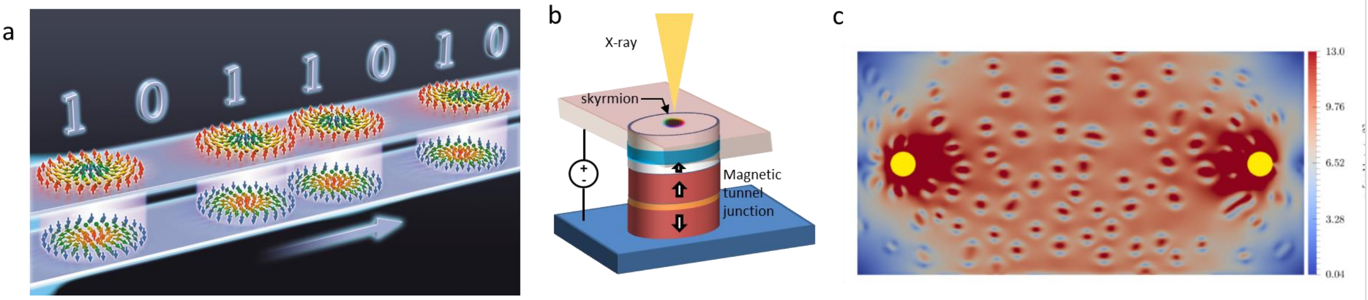

Figure 2a Antiferromagnetic skyrmions encoding the information in a racetrack [2] b skyrmion in a magnetic tunnel junction observed via scanning transmission x-ray microscopy [3]. c Proposal of skyrmion reservoir computing device [4]

Recently, unconventional computing schemes, such as neuromorphic or reservoir computing, have been proposed where skyrmions are used to solve standard complex machine learning problems (classification, prediction) with very low energy consumption (Fig. 1c) [4]. The nanometer size of magnetic skyrmions and their non-volatility would allow gains of several orders of magnitude in computing speed and delay compared to current neuromorphic computing devices.

In this internship, we propose to demonstrate the potential of magnetic skyrmions for neuromorphic computing by showing the basic functionalities of logic devices based on the manipulation of magnetic skyrmions for non-conventional computing. The first step will be to fabricate neuromorphic devices based on the manipulation of skyrmions and demonstrate their basic functionalities. The final objective will be the demonstration of the resolution of standard learning problems, for instance voice recognition.

Work program & Skills acquired during internship

The internship will be based on all the methods and experimental techniques used for the development and characterization of spintronic devices: sputtering deposition of ultra-thin multilayers and the characterization of their magnetic properties by magnetometry methods, then nanofabrication of nanostructures by electron beam lithography and ion etching. The nanofabrication will be performed at the PTA nanofabrication platform located in the same building as the Spintec laboratory. The manipulation of the skyrmions in the nanostructures will then be characterized by electrical measurement of Kerr effect optical magnetic microscopy (MOKE). The data will then be analyzed using neural network algorithms in order to achieve pattern recognition tasks.

Reference

[1] O. Boulle *et al.*, Nat Nano 11, 449 (2016).
[2] V-T Pham, Science, 384, 693 (2024), "Le skyrmion, cette étrange structure qui pourrait bousculer l'électronique" Journal Lemonde 23 avril 2024, ," Les skyrmions, des nanobulles magnétiques pour remplacer l'électronique, atteignent des vitesses records", France culture, 19 avril 2024
[3] J. Urrestarazu Larranaga et al., Nano Letters, 24, 3557 (2024)

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Requested background: Master 2
Duration: 6 months
Start period: Feb/ March 2027
Possibility of PhD thesis : NO

Antiferromagnetic tunnel junctions for memory and neuromorphic application

Context

The accelerating digital transition and the exponential growth in data demand are driving a need for emerging non-volatile memory technologies that combine high speed, low energy consumption and high endurance. Spintronic memories, such as MRAM, have made significant strides in addressing these challenges, offering non-volatility, high endurance, and CMOS compatibility. However, conventional MRAM devices are limited by relatively slow switching speeds (10 ns), and susceptibility to external magnetic fields, which hinder their performance in many applications. During the last decade, antiferromagnets (AF) have raised a renewed interest due to their potential advantages over ferromagnets for memory and microwave applications. Antiferromagnetic materials are magnetic internally, but the direction of their ordered microscopic moments alternates between individual atomic sites. The resulting net zero magnetic moment makes the magnetism of antiferromagnets invisible from the outside. This also implies that if information were stored in antiferromagnetic moments, it would be insensitive to disruptive external magnetic fields, and the antiferromagnetic element would not magnetically affect its neighbors, regardless of the density of the elements arranged in a device. The intrinsic high frequencies (THz) of antiferromagnetic dynamics are another property that distinguishes antiferromagnets from ferromagnets. These properties make antiferromagnetic magnets promising for storing information in memories, combining high information density with very fast, low-energy writing. However, the zero magnetic moment of antiferromagnets and vanishing spin current polarization, makes them difficult to manipulate and detect electrically.

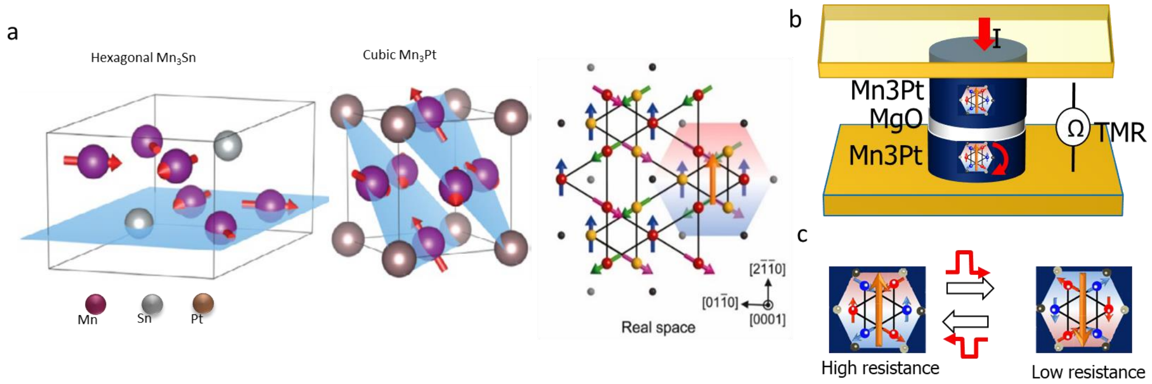

Figure 3 (left) Mn_3Sn and Mn_3Pt non -collinear AF (NCAF) spin textures (Kagome planes in blue) (right) Magnetic structure of Mn_3Sn. The chiral spin structure can be described by a cluster octupole made of six moments (orange arrow and colored hexagon) . (b-c) **AF memory** The bit is encoded in the direction of the AF octupole. The write operation is achieved by injecting a current pulse. This leads to reversal of the octupole direction. The readout is performed by measuring the junction resistance exploiting the TMR effect.

First steps toward the realization of such devices were recently done with full antiferromagnetic tunnel junctions (AF-MTJs) based on Mn_3Sn and Mn_3Pt non -collinear AF (see Figure1) with TMR reaching 100 % at room temperature. However, the demonstration of both read and write operations in the same device, i.e the writing of the bit using electrical current and its electrical detection using TMR effect has not been demonstrated yet. This master thesis project aims to demonstrate a memory based on an AF-MTJ, i.e the readout via TMR effect and its electrical writing via spin transfer torque.

Work program & Skills acquired during internship

A first aim of the thesis will be to optimize the growth of Mn_3Pt based AF MTJ via magnetron sputtering. This will include the optimization of the growth conditions (power, temperature) and the characterization of the structural, magnetic and electronic properties using x-ray diffraction techniques, magnetometry measurements (VSM, SQUID) and magneto-transport measurements. Then, sub-micronic pillar will be patterned at the PTA cleanroom using standard nanofabrication techniques. Then high frequency magneto-transport measurements will be performed to characterize the tunneling magneto-resistance effect as well as the electrical manipulation of the AF order.

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Requested background: Master 2
Duration: 6 months
Start period: Feb/ March 2027
Possibility of PhD thesis : YES

Digital circuit design based on ferroelectric spin-orbit devices

Context. With the quick rise in energy consumption of the information and communication technology (ICT) sector expected to reach up to 15% of the total global electricity demand by 2030, giants of the microelectronics industry are actively searching for alternatives to existing technologies. New paradigms of computation beyond-CMOS and von Neumann architectures such as in-memory computing and spintronic-based components seem very promising solutions combining high computational density with drastically reduced power consumption. Among these approaches, Intel recently proposed the magneto-electric spin-orbit (MESO) logic device[1], a beyond-CMOS logic concept combining magneto-electric switching with spin-orbit readout to enable low-voltage, non-volatile logic operation. More recently, we demonstrated in two articles (Nature & Nature Electronics[2,3]) the concept and physical foundations for a new type of non-volatile device, coined FESO, which combines ferroelectrics (FE) and spin-orbitronic (SO) phenomena. Their interplay enables electrically-switchable and highly efficient signal transduction with ultra-low power operation, without relying on energy-costly mechanisms such as magnetization switching, as the device proposed by Intel.

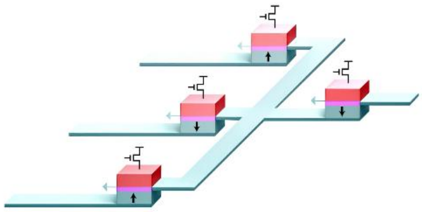

Figure 4. Schematic illustration of a majority gate based on FESO devices.

Such devices can be used advantageously to perform logic operations when combined (cf. fig. 1). The resulting combination of ultra-low power and compact computing makes FESO particularly attractive in the context of AI hardware, where it can find its place both as a low-power replacement for elements of conventional architectures and as a building block for new computing paradigms such as In-Memory Computing or Neuromorphic Computing.

Work program & Skills acquired during internship. The Internship (and possible PhD) project, aims to investigate the potential of the intrinsic non-volatility of FESO devices for next-generation digital architectures. This includes both identifying existing digital architectures that could significantly benefit from a FESO-based implementation, and exploring entirely new types of architectures enabled by non-volatile logic. Building on previous work in our laboratory, which established a library of individual non-volatile logic functions exploiting the advantages of FESO and demonstrated their reliable interconnection, the student will investigate and further develop architectural concepts already proposed within the group. This work will primarily rely on digital-level modeling, algorithms, and representative benchmarks, complemented by analog-level verification, to quantitatively assess their performance, advantages, and overall potential.

The intern will be involved in the full research and development process, from low-level digital design to the simulation and benchmarking of larger demonstrator circuits, including the writing of papers and patents. The intern will also interact regularly with other members of the laboratory working on the design of electrical circuits and AI systems based on such devices. The project will benefit from the existence of a large collective momentum in our teams towards the development and integration of ferroelectric-based devices, with ongoing ANR and EU projects, and more importantly with a valorization project with the start-up Nellow, based on this technology. The student will be working within the IC design team of SPINTEC and in strong interaction with the Topological Spintronics team and the startup.

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Possibility of PhD thesis : YES

Memristor arrays based on ferroelectric devices

Context

Memristor arrays have emerged as a promising hardware platform for neuromorphic computing [1]. By emulating the adaptive and parallel processing capabilities of synapses, memristors enable energy-efficient, in-memory computation and can support complex learning algorithms directly in hardware. This approach contrasts with traditional von Neumann architectures, which are limited by the energy and latency costs of shuttling data between memory and processing units.

In this context, ferroelectric memristors offer distinct advantages. Ferroelectric materials, which exhibit switchable polarization states, provide non-volatile memory, low power operation, and high scalability. Their ability to achieve analog resistance modulation—mimicking synaptic plasticity—makes them particularly well-suited for implementing artificial neural networks with high density, fast operation, and low energy consumption [2,3]. Additionally, ferroelectric devices can enable multi-level data storage and robust retention, further enhancing the efficiency and performance of neuromorphic systems.

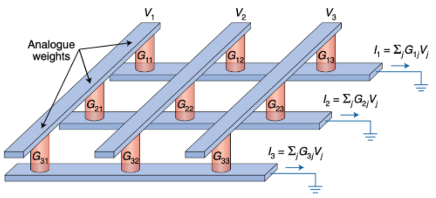

Figure 5: Schematic illustration of our ferroelectric-based memristor arrays

At the cross-road between ferroelectricity and quantum physics and materials engineering, such devices allow to modulate very simply their resistance in a non-volatile way using electric fields, thus without resorting to energy-costly mechanisms of other currently studied memristor implementations such as magnetization switching or phase-change. This makes ferroelectric memristors very good candidates for ultralow-power neuromorphic Artificial Intelligence architectures.

Work program & Skills acquired during internship

The Internship (and possible PhD) project aims at exploring the possibilities offered by these features, in particular for the development of FE-based memristor arrays. The student will characterize the basic materials properties and the memristive character of ferroelectric devices and ultimately integrate such devices into memristor arrays. The intern will be involved in the full process from the nanofabrication and electrical measurement of single devices and small memristor arrays to the writing of papers and patents. The intern will also interact regularly with other members of the team working on the design of electrical circuits and AI systems based on such devices. The project will benefit from the existence of a large collective momentum in our teams towards the development and integration of these devices, with ongoing ANR and EU projects, and more importantly with a valorization project with the start-up Nellow, based on this technology.

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Possibility of PhD thesis : YES

Note